Treatment strategies of arterial steal after arteriovenous access

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Introduction: **Ischemic steal syndrome (ISS) associated with arteriovenous (AV) access is rare but can result in severe complications. Multiple techniques have been described to treat ISS with varying degrees of success. This study compares the management and success associated with these techniques.**

Methods: **Patients with ISS between June 2003 and June of 2008 at the University of Pittsburgh Medical Center were retrospectively reviewed. Demographics, type of AV access, management technique, and success of intervention were recorded. Success was defined as resolution of ISS symptoms while preserving access function. One hundred consecutive AV access procedures were reviewed for comparison. Data were analyzed using χ^2 test, Fisher's exact test, and Student's *t* test. The study was approved by our institutional review board.**

Results: **A total of 114 patients with ISS had a mean age of 65 years (range, 20-90 years), were predominantly female (66%), diabetic (61%), and with a brachial origin fistula (69%). Risk factors for ISS included coronary artery disease (CAD; $P < .001$), hypertension ($P < .001$), and tobacco use ($P = .048$). Women were noted to have a brachial origin access more frequently than men (odds ratio [OR], 3.1; $P = .009$). Forty-four patients with mild steal were observed. Seventy patients underwent 87 procedures. Procedures performed included ligation (n = 27), banding (n = 22), distal revascularization and interval ligation (DRIL; n = 21), improvement of proximal inflow (n = 9), revision using distal inflow (RUDI; n = 4), and proximalization of arterial inflow (PAI; n = 3). Early procedures (<30 days from the index fistula) were mostly ligation (50%) or banding (38%), while DRIL was the most frequent choice for late interventions (41%). Banding had a high failure rate (62%) and was the most common reason for reintervention (8 of 11, 73%) and DRIL had a better success rate than banding ($P \leq .05$).**

In our current practice, 18% of patients had an AV fistula with the proximal radial artery (PRA) as the inflow source, while this type of fistula accounted for only 2% of all ISS patients. Ligation resolved symptoms in all patients, but the AV access was lost.

Conclusions: **Risk factors for development of ISS include CAD, diabetes, female gender, hypertension, and tobacco use. Among various options to treat ISS, banding has a low success rate and high likelihood for reintervention, while DRIL is particularly effective although not uniformly. Less invasive treatment options such as RUDI and PAI may be quite effective in treating ISS. Use of the PRA as the inflow source may decrease the incidence of ISS. (J Vasc Surg 2011;54: 162-7.)**

An estimated 340,000 patients in the United States are maintained on hemodialysis, and a significant amount of the health care expenses related to the care of these patients is utilized to treat the complications related to hemodialysis access. Although ischemic steal syndrome (ISS) following arteriovenous (AV) hemodialysis access procedures is relatively rare, it remains a serious complication with varied treatment options and outcomes. The need for surgical treatment of ISS is based on the clinical severity of the symptoms. The majority of patients who have steal develop mild paresthesias that requires no treatment; however, patients with moderate-to-severe ISS have symptoms such as persistent pain, motor dysfunction or ulceration, and generally require treatment.[1-3] Early diagnosis and treatment of moderate-to-severe ISS can prevent permanent motor dysfunction as well as severe ischemic neuropathy and tissue loss. Previously, identified risk factors for the development of ISS include diabetes mellitus, female gender, advanced age, prior ipsilateral AV access placement, and peripheral arterial disease.[4] However, the development of ISS cannot be accurately predicted based on any particular constellation of risk factors. ISS seems to occur more frequently with brachial origin fistulas than with radial or ulnar origin fistulas.[4]

Surgical treatment options for moderate-to-severe ISS can be divided into three broad categories: ligation, restriction of flow, and rerouting of arterial inflow. Ligation is effective in treatment of the ISS but results in loss of the access. Banding[5] and plication[6] are used to restrict flow through the access and improve native distal arterial flow; however, these techniques have had variable success in

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accomplishing the goals of resolving the ISS and preserving a functional AV access. Another option to restrict flow into the AV access involves revision of the arterial anastomosis to a more distal origin, such as the radial artery (revision using distal inflow [RUDI]).[7] More complicated interventions include distal revascularization and interval ligation (DRIL),[8-10] and proximalization of the arterial inflow (PAI).[11,12]

The ideal intervention for ISS should result in prompt resolution of the steal symptoms with preservation of a functional AV access. Although several series have documented the effectiveness of the DRIL procedure, it is an involved procedure that requires ligation of the brachial artery and a vein bypass to the distal brachial artery. This study was designed to review the management and success associated with various techniques for treatment of ISS following AV access in a large group of patients at our institution. We sought to determine if the various treatment options for ISS were effective and if there were differences between treatment strategies. We also attempted to identify risk factors associated with the development of ISS.

METHODS

We retrospectively reviewed all patients who underwent a corrective procedure for ISS related to a functional AV access between June 2003 and June of 2008 at the University of Pittsburgh Medical Center following approval by the institutional review board. We compared this group to a control group of 100 consecutive AV access patients taken from a time period contemporary to the ISS group. This control group represented a random selection of patients from all institutional surgeons doing AV access and encompassing a variety of procedures. All surgeons performing AV access in the institution are board-certified vascular surgeons. Electronic medical records, hospital charts, operative notes, and office charts were reviewed. Demographic data, type of AV access, operative details (type of access and arterial origin), onset of symptoms, and presence of various risk factors such as coronary artery disease (CAD), peripheral arterial disease, diabetes mellitus, hypertension, hyperlipidemia, tobacco abuse, and prior access procedure were noted. Clinical outcomes were recorded, including resolution of ISS symptoms, preservation of a functional access, and morbidity and mortality related to the procedure. We defined success as resolution of the ISS and preservation of a functional AV access.

Surgical treatment was provided by the group of board-certified vascular surgeons on staff at the University of Pittsburgh Medical Center. The diagnosis of ISS was based on clinical symptoms, and noninvasive testing was selectively performed in equivocal cases or to confirm ISS. Patients with mild (grade 1 – slight coldness and numbness, mainly during dialysis) steal were observed. Surgical treatment was reserved for patients with moderate (grade 2 – severe numbness and pain) to severe (grade 3 – digital gangrene, motor dysfunction) steal, and these are the patients that make up the cohort of this study. The treatment method was at the discretion of the surgeon. Patients were assessed within 30 days postoperatively after any corrective procedure and then as needed. Nominal variables were compared using χ^2 test or Fisher's exact test, and continuous variables were compared with Student's t test. The Wilcoxon rank-sum test was used to compare unmatched data pairs. A P value of .05 or lower was considered significant.

Table I. Demographics and comorbidities

Clinical characteristics	*Steal patients (n = 114)*	*Current practice (n = 100)*	P *value*	*Odds ratio*
Age (years)	64.6	61.3	.11	N/A
Female gender	66%	52%	.040	1.78
Tobacco use	27%	16%	.048	2.0
Diabetes mellitus	61%	45%	.016	1.9
Hypertension	95%	64%	<.001	2.8
Hyperlipidemia	37%	25%	.057	1.8
Peripheral vascular disease	38%	21%	.008	2.3
Coronary artery disease	54%	31%	<.001	2.7

RESULTS

A total of 114 patients with ISS were identified in the study period. There were a total of 922 patients undergoing access procedures during the same period. In the ISS group, mean patient age was 65 years (range, 20-90 years). Females accounted for 66% of the population, and 61% of the patients were diabetic. The control group of patients was comparable by age with a mean age of 61 years (P = .11) but were significantly less likely to be diabetic (45%; P = .016) and female (52%; P = .040; Table I). Risk factors that were found more commonly in the ISS group included CAD (P < .001), hypertension (P < .001), and tobacco use (P = .048; Table I). At 6 months, 49% of control patients had a working fistula, 34% had either not matured or were not being used, and 17% of patients were lost to follow up or died. In the control group, fistula maturation rate with use of the proximal radial artery was 47% compared with 76% with use of the brachial artery. These differences did not achieve statistical significance.

Sixty-nine percent of the patients with ISS had a brachial artery origin for their fistula. Patients with steal were more likely to have upper arm fistulas compared with patients without steal. Women were noted to have a brachial origin access more frequently than men (odds ratio [OR], 3.1; P = .009). Only 16% of steal patients had a prosthetic graft, and this was comparable to the control cohort where 15% of patients had a prosthetic access (Table II).

Of the 114 patients with ISS, 44 patients had a mild (grade one) steal and were observed. Seventy patients with moderate-to-severe ISS underwent intervention for a total of 87 procedures. Patients had these procedures performed from 0 to 3,431 days after the index fistula procedure, with

Table II. Access configurations in steal patients and current practice

AV access	*Steal*	*Current practice*	P *value*	*Odds ratio*
Autogenous brachial-cephalic upper arm direct access	50% (57/114)	23% (23/100)	<.001	3.348
Autogenous brachial-basilic upper arm transposition	19% (22/114)	10% (10/100)	.057	N/A
Autogenous access, brachial artery origin	69% (79/114)	33% (33/100)	<.001	4.583
Autogenous radial-cephalic direct wrist access	13% (15/114)	18% (18/100)	.328	N/A
Autogenous radial-cephalic direct proximal forearm access	2% (2/114)	18% (18/100)	<.001	0.081
Use of prosthetic conduit	16% (18/114)	15% (15/100)	.873	N/A

Current practice results do not include 16 miscellaneous AV access types, including lower extremity access and arteriovenous fistula with ulnar artery origin.

Table III. Success rate of various management techniques

Management technique	*Number of patients who were managed with the technique*	*Patients available for follow-up*	*Success rate (95% confidence interval)*
Ligation	27	25	0% (N/A)
Banding	22	21	38% (17%-59%)
Distal revascularization and interval ligation	21	20	80% (62%-98%)[a]
Improve inflow	9	7	43% (N/A)
Revision using distal inflow	4	3	100% (N/A)
Proximalization using arterial inflow	3	3	100% (N/A)
Distal revascularization	1	1	100% (N/A)

[a]Statistically significant at $P \leq .05$.

an average intervention time of 310 days (standard deviation, 636 days) and a median time to intervention of 72 days.

The procedures performed included ligation (n = 27), banding (n = 22), DRIL (n = 21), improvement of proximal inflow (n = 9), revision using distal inflow (n = 4), and proximalization of arterial inflow (n = 3; Table III). One patient received a distal revascularization procedure without an interval ligation, which was successful in addressing the patient's steal symptoms. Although ligation resulted in resolution of ISS, it also resulted in loss of the fistula and was therefore not considered effective. DRIL was effective in resolution of the ISS in 90% of patients, although loss of the fistula occurred in an additional 10% of the patients, resulting in an overall effectiveness of 80% (Fig). DRIL had a better success rate than banding ($P \leq .05$; Fig).

Banding had a low success rate, with 19% of the fistulas thrombosing and 48% of patients with continued symptoms of steal. Of note, one patient suffered both thrombosis of the fistula and continued steal symptoms, leading to an overall failure rate of 62%. The authors generally performed banding by the basic technique involving either plication of the vein just beyond the anastomosis for a length of approximately 1 cm, or restricting the flow through this segment of the vein by wrapping a segment of expanded polytetrafluoroethylene (ePTFE) around the vein to narrow it. The extent of plication was determined by either return of a palpable pulse or conversion from mono- to-biphasic Doppler signals at the level of the wrist.

Of note, the majority of reinterventions (8 of 11; 73%) were performed in patients who underwent banding. Although the number of patients in these groups was low, both RUDI (100%) and PAI (100%) were highly successful in resolution of the ISS and preservation of the access. The majority of early (<30 days from the index fistula) procedures were ligation (50%) or banding (38%), while DRIL was the most frequent choice for late interventions (41%).

Hemodynamic data were not routinely collected on patients with suspected steal. In patients in whom this data were available, average digital pressures before and after DRIL and banding showed that the average preintervention pressure in the DRIL group was 43 mm Hg and in the banding group was 33 mm Hg. After DRIL, the average pressure rose to 75 mm Hg. In the banding group, this rose to 44 mm Hg. Statistical comparison between groups was not able to be performed secondary to small sample size. There was a significant difference ($P = .02$) in pre- and post-DRIL patients, although these data do not reflect match pairs. In the small number of patients who had postintervention testing, there was not a direct relationship between finger pressures, pulse volume recording waves, and function. Only one tested patient had postintervention normal finger pressures and complete resolution of hand symptoms. This may represent a selection bias, with only those patients with unresolved symptoms having repeat testing performed.

DISCUSSION

This study illustrates the success rate of various techniques to treat ISS in a large group of patients at a single institution as well as potential risk factors for the development of ISS. In our analysis CAD, diabetes mellitus II, female gender, hypertension, and tobacco use all predicted steal. Clinical characteristics that were found to be statistically significant risk factors for ISS in our series mirror those

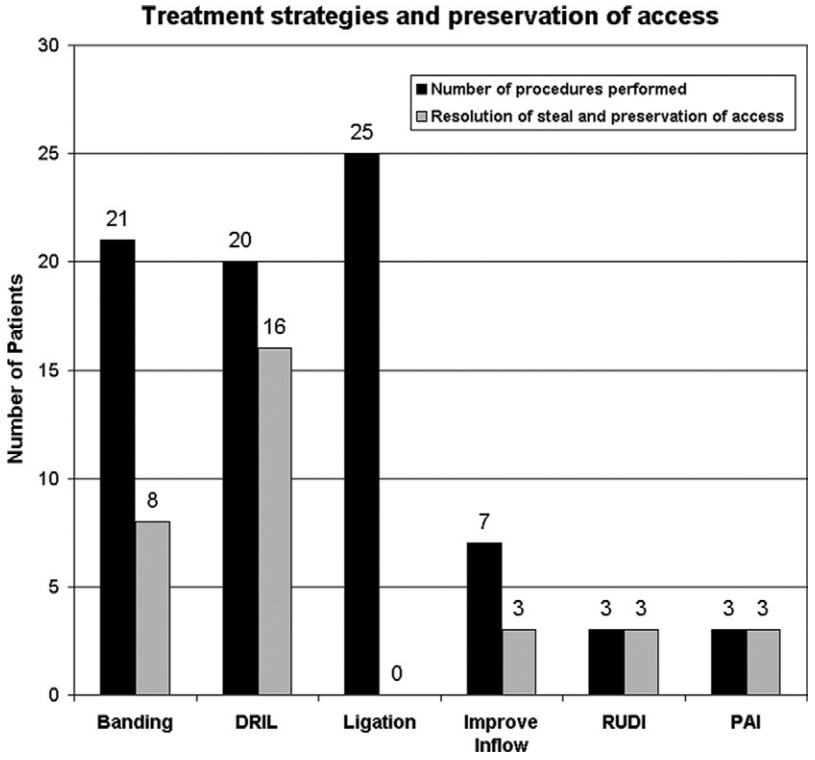

Fig. Banding had a low success rate. Distal revascularization and interval ligation (*DRIL*) was quite effective in treatment of steal and ligation resulted in loss of the fistula and was considered ineffective. Both revision using distal inflow (*RUDI*) and proximalization of the arterial inflow (*PAI*) were highly successful, however, the numbers were small. Patient numbers reflect number of patients available for follow-up.

that have been described in previous series. Age at time of operation, body weight, and use of prosthetic grafts were not found to be statistically significant for development of ISS.

Numerous studies have described the success of the DRIL procedure to treat ISS.[8-10] DRIL was found to have a better rate of success in treating ISS compared with banding ($P \leq .05$). Although the DRIL procedure is quite effective in the treatment of steal, it is not uniformly effective. In addition, this procedure potentially places the hand perfusion at risk if the bypass fails. The procedure is usually performed under general anesthesia and requires harvest of an adequate segment of vein for bypass. Complications related to the DRIL procedure have been reported and include failure of the DRIL to salvage the hand. In our experience with DRIL, we had one serious complication in a patient that already had some hand necrosis prior to the DRIL procedure; the necrosis did not resolve, and after the DRIL, the hand required multiple debridements and eventual amputation. This patient was not included in our analysis, as the ISS occurred after the study period. Overall, DRIL, despite its complexity and risks, worked well and was certainly better than banding.

Banding and plication rely on the premise that increasing the resistance through the fistula will result in increased perfusion to the extremity distal to the origin of the fistula. Results using these techniques vary, with most studies concluding that they are an overall ineffective treatment.[13] One recent study[6] did show better success with plication; however, this was a small series of seven patients, and the surgeons relied on subjective measures such as quality of the Doppler signal to guide the degree of plication. In our own study, banding had a low success rate (38%), and the highest rate of reintervention (8/21, 38%) among all the treatment types. We believe that this is related to the problem of gauging the success of the initial banding procedure to adequately restore sufficient arterial flow to the hand. In addition, if the fistula is banded to the level that adequate flow is restored to the hand, this often results in either loss of the fistula or flow through the fistula that is inadequate for effective hemodialysis.

Two relatively more recent procedures seem to hold promise. RUDI is accomplished by ligating the AV anastomosis and revising the arterial inflow to a more distal source such as the radial or ulnar artery, either with an interposition graft or by direct anastomosis of the outflow vein to the new inflow artery. Success of this technique has been reported in a small series of patients.[7] The PAI technique involves disconnection of the arterialized fistula close to the AV anastomosis and construction of a new inflow to the efferent vein from a more proximal artery such as the axillary artery using a small-diameter ePTFE graft.[11,12] The

drawback of this approach is that this effectively converts an autogenous fistula to a prosthetic access associated with limited patency rates, potential stenosis at the anastomosis between the prosthetic and native materials, and complications such as infection. However, the authors describe access of the native vein for hemodialysis access, unless there is a limited amount of vein available for access in which case the prosthetic graft is accessed as well.

Both RUDI and PAI are attractive options because they preserve native arterial continuity. In addition, they can generally be performed under local anesthesia without requiring extensive vein harvest. This is well tolerated in the majority of dialysis-dependant patients who are often elderly with multiple comorbidities. In our series, both RUDI and PAI were quite successful in resolving the ISS symptoms and preserving a functional access. RUDI has been described using a segment of saphenous vein interposition graft; however, depending on the anatomy of the fistula and the proximity of the anastomosis to the proximal radial artery, this can be performed by disconnecting the brachiocephalic anastomosis, mobilizing a short segment of the cephalic vein, and reanastomosing the cephalic vein to the proximal radial artery. We were able to accomplish this in all of our patients undergoing RUDI. This procedure is minimally invasive and can be accomplished under local with monitored anesthesia care. In fact, in our review, of all the patients that developed steal, only a minority (2%) had the proximal radial artery used as in inflow source, whereas use of the proximal radial artery represented 18% of patients in our current practice, suggesting a trend toward preferential use of the proximal radial artery as the inflow for the fistula whenever possible. This also suggests that use of the proximal radial artery as opposed to the brachial artery may result in a significantly lower incidence of steal. Although the differences are not statistically significant, possibly related to the small sample size, our results suggest that there may be a tradeoff as far as a lower rate of fistula maturation (47%) with use of the proximal radial artery as the inflow source compared with the maturation rate (76%) with use of the brachial artery.

The most straightforward method of treating steal is to identify any inflow lesions and correct these either via endovascular or open means. However, with use of adequate preoperative physical examination and noninvasive imaging studies, this generally represents a small proportion of patients that develop steal.

Some groups have described the "pre-emptive" DRIL,[8] which seems to be a radical approach to establishing hemodialysis access in this group of patients with multiple comorbidities. A better strategy would be to try to use the proximal radial artery whenever possible as the inflow source for the fistula to begin with. This segment of the radial artery is generally undiseased, of decent caliber, and easy to access via the standard antecubital incision used for brachiocephalic fistula procedures.

Our study examines a large group of patients with ISS, and we have identified risk factors for ISS that may be helpful to surgeons as they plan AV access procedures. We have also discussed the variety of treatment strategies to deal with the difficult problem. However, this study is limited by the inherent nature of its retrospective design. It is possible that not all ISS patients were identified, and data collected on our ISS patients were not uniform. Not all the ISS patients had noninvasive testing, and follow-up was not standardized. In addition, this work is limited by the fact that some of the ISS population consists of patients that were referred from outside institutions at various stages of hand ischemia. This makes comparison across the ISS population more difficult, as decision making at the time of the initial operation cannot be known, and the success of various treatment options is dependent on the degree of ischemia and disability at the time of presentation. With an overall population of over 900 patients that underwent AV access in this time period, retrospective data collection on this group becomes impractical. Our control group was taken from a group of consecutive patients within the same time period. There is a much lower incidence of ISS in this group due to the rarity of ISS. Selection of control groups in a retrospective study is always a challenge, and our choice of contemporary controls may not be perfectly matched to the patients with ISS.

In conclusion, patients at risk for steal include those who have a history of smoking, have CAD, are female, and who have a proximal fistula, either autologous or prosthetic.

Among the various options used to treat ISS, banding has a low success rate and high likelihood for reintervention, and ligation pays the price of loss of the access. DRIL is quite effective in treatment of ISS but not uniformly and is a more extensive procedure that potentially jeopardizes the hand. Less invasive treatment options such as RUDI and PAI may be quite effective at treating the ISS while maintaining native arterial flow to the hand. Use of the proximal radial artery as the inflow source may decrease the incidence of ISS.

AUTHOR CONTRIBUTIONS

Conception and design: NG, ED, MM
Analysis and interpretation: NG, TY, GK, ED, SL, RC, MM
Data collection: NG, TY, ED, GK
Writing the article: NG, TY, ED
Critical revision of the article: NG, TY, GK, ED, SL, RC, JC, MM
Final approval of the article: NG, TY, GK, ED, SL, RC, JC, MM
Statistical analysis: NG, TY, ED
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INVITED COMMENTARY

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This study from the University of Pittsburgh addresses an important clinical problem after hemodialysis access creation: the ischemic steal syndrome (ISS). It is one of the largest series in the literature.[1]

The pathophysiology of ISS is worth reviewing. The magnitude of blood flow through an arteriovenous fistula is a function of the diameter of both the fistula and the donor artery. Fistulas are classified by the fistula diameter relative to that of the donor artery. Small fistulas are defined as having a diameter <75% of the diameter of the inflow artery. In small fistulas, the primary determinant of the magnitude of fistula flow is fistula resistance, which varies with the fourth power of the diameter. The natural history of small fistulas is thrombosis. Large fistulas have a diameter >75% that of the donor artery, and the magnitude of blood flow tends to be independent of fistula resistance and diameter. In large fistulas, flow is determined primarily by the relative resistances of the peripheral vascular bed, the donor artery, and the collateral circulation. Most surgically created fistulas are of the large variety in order to provide sufficient blood flow (approximately 600 ml/minute) for dialysis.[2,3] Nearly all surgically created fistulas create physiological steal; ISS results when distal arterial perfusion is inadequate to meet tissue metabolic requirements.[2]

Thus, it is no surprise that banding, which increases fistula resistance, is unlikely to achieve the dual goals of ISS treatment (ie, preservation of the access and relief of the ischemia). In this series, banding had poor outcomes. Nineteen percent of fistulas thrombosed after banding, and 48% of patients had persistent ischemia; 73% of reinterventions were performed in patients who underwent banding. Distal revascularization and interval ligation (DRIL) had a statistically better success rate than banding ($P \leq .05$) and was effective in resolution of ISS in 90% of patients. DRIL remains the procedure of choice for treatment of ISS.[4]

I would urge future investigations of ISS to include hemodynamic data (digital arterial pressure measurements with and without fistula compression), which in my view, are essential to confirm the diagnosis and quantify severity.[2] While hemodynamic data were not routinely collected in this series, it is interesting to compare pre- and postoperative hemodynamics for those in whom they were available. Following the DRIL procedure, digital pressures increased from 43 to 75 mm Hg; after banding, the corresponding increase was only from 33 to 44 mm Hg. This difference was statistically significant and likely accounts for the failure of a substantial number of banded patients to improve. The authors report some experience with revision using distal inflow (RUDI) and proximalization of arterial inflow (PAI). While the reported results were excellent, patient numbers were low. These procedures likely work in a manner analogous to the DRIL procedure, by altering relative resistances (either by adding length or reducing donor artery diameter) rather than by increasing fistula outflow resistance. Such procedures, based on the physiology of ISS, are most likely to succeed.

This is a well-written study of ISS. Hopefully, it will lay banding to rest. Future investigations, especially with the newer RUDI and PAI procedures, should include hemodynamic data and sufficient follow-up to allow comparison with the well-established DRIL procedure.

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